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REPORT

SATELLITE BROADCASTING: co-channel protection ratios for f.m. television

No. 1971/19

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

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Research Department Report No. **1971/19**

SATELLITE BROADCASTING: CO-CHANNEL PROTECTION RATIOS FOR F.M. TELEVISION

There is an increasing amount of international discussion on the standards which should be adopted for television broadcasting from satellites, and on the extent to which different transmissions can be accommodated within the limited frequency band which may be available. It is likely that a frequency modulation system will be employed, with the sound signal transmitted on a sub-carrier added to the vision signal.

The report considers the most suitable amplitude for this sub-carrier, and describes subjective tests to provide data for establishing the acceptable level of interference between f.m. television transmissions occupying the same frequency channel.

Although there are as yet no plans for satellite broadcasting to the U.K., it is important for broadcasters to know the basic criteria, such as the protection ratios discussed in this report, for evolving suitable frequency assignments to different countries. The World Administrative Radio Conference on Space Telecommunications, June 1971, is expected to take only the first step by allocating a frequency band around 12 GHz, and possibly certain other bands, for television broadcasting from satellites. After the conference it will be desirable for discussions on detailed assignments for broadcasting services to take place quite soon, in order to ensure the most effective and equitable use of the band in the long term.

AB
May 1971

(RA-79)

RESEARCH DEPARTMENT

SATELLITE BROADCASTING: CO-CHANNEL PROTECTION RATIOS FOR F.M. TELEVISION

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SATELLITE BROADCASTING: CO-CHANNEL PROTECTION RATIOS FOR F.M. TELEVISION

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SATELLITE BROADCASTING: CO-CHANNEL PROTECTION RATIOS FOR F.M. TELEVISION

Summary

Some of the parameters required for an f.m. system suitable for direct television broadcasting from a geo-stationary satellite are discussed. Using a system with such parameters, the results of subjective tests on co-channel interference are presented, and a simple formula is derived relating protection ratio and picture impairment grade.

1. Introduction

When planning the possible development of direct television broadcasting from geo-stationary satellites, it is essential to know the acceptable levels of interference from other television transmissions occupying the same frequency channel. These levels will depend on the type and parameters of the modulation system employed. Frequency modulation (f.m.) appears to offer a good compromise between satellite power requirements, bandwidth and simplicity of the receiver adaptor, and studies[1] have indicated that, using bandwidths of the order of 30 MHz, it would enable efficient use of the radio spectrum to be made.

In spite of the widespread use of f.m. on television relay links, there is only a limited amount of information available on the effects of co-channel interference, particularly with colour pictures. This report gives the results of subjective tests which have been carried out to provide more reliable information for the case of 625-line, Standard I PAL transmissions.

2. Previous work

Some subjective test results have been given[2] for the 525-line NTSC system, with pre-emphasis* of the wanted picture, and with an added carrier-dispersal waveform on the interfering signal. One conclusion from these tests was that the subjective impairment did not depend significantly on the amount of modulation of the interference. Other results[2] were given for the 625-line system, viewed on a monochrome monitor, and they also indicated that modulation of the interference had little effect on the impairment, at least at low levels of impairment. The 625-line tests also suggested that no significant advantage is obtained by adding energy-dispersal waveforms.

3. Suitable parameters for a frequency-modulation system

3.1. Bandwidth and deviation

Consideration of the best use of the total bandwidth which is likely to be available for s.h.f. direct satellite broadcasting has led to the conclusion[1] that the bandwidth to be allowed for each channel should preferably be in the range of 20 to 32 MHz. Thus, applying Carson's rule for the bandwidth occupied (viz., the peak-to-peak deviation plus twice the maximum modulation frequency), we find that the peak-to-peak deviation may be about 8 to 20 MHz. A certain proportion of this must be allocated to the sound subcarrier, as discussed in Section 3.2, and the maximum modulation frequency has been taken as 6 MHz, since this would be a suitable subcarrier frequency.

3.2. Sound subcarrier

From the point of view of receiver design, the most convenient method of transmitting the sound accompanying the television programme is by means of a subcarrier added to the composite video signal. If this subcarrier is at 6 MHz, and is frequency-modulated by the sound programme to a peak deviation of 50 kHz (i.e. the *peak-to-peak* deviation is 100 kHz), the arrangements at the receiver will be simplified, as the existing inter-carrier sound circuits can be used. We assume that it is desired to achieve an unweighted sound signal-to-noise ratio (s.n.r.) of 60 dB, when the vision unweighted s.n.r. is 42 dB. It is shown in the Appendix that in order to achieve these conditions simultaneously, the sound subcarrier is required to deviate the main carrier to about 13% of the total deviation, leaving 87% for the composite video signal.**

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* In this report, mention of pre-emphasis will be taken to imply the use of corresponding de-emphasis in the receiver.

** In this report the term 'composite video signal' means the vision luminance and chrominance components together with the synchronising pulses, but it does not include the sound subcarrier.

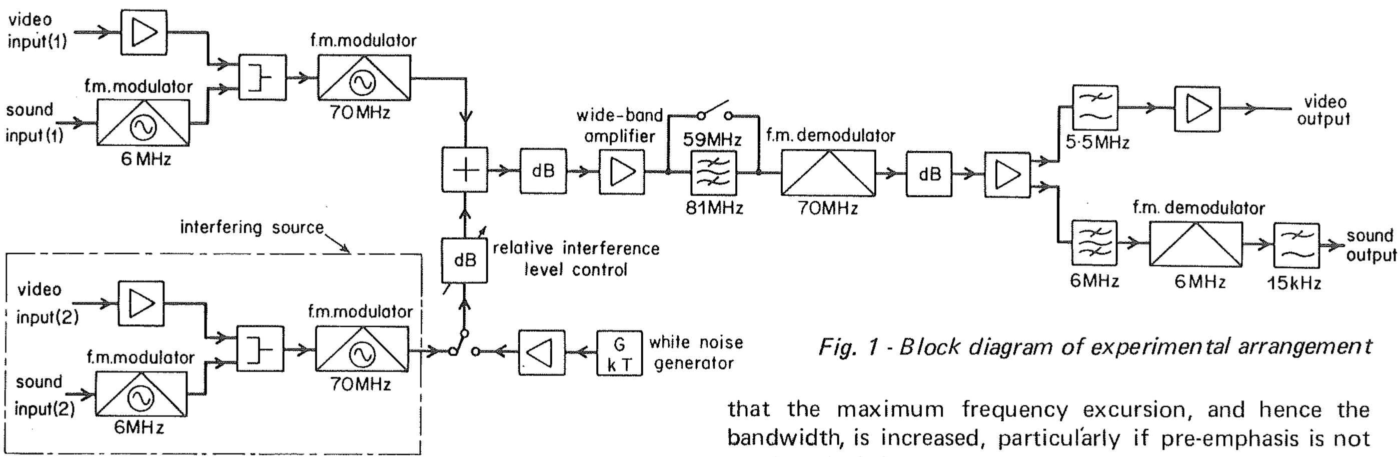


Fig. 1 - Block diagram of experimental arrangement

An alternative criterion for defining the amplitude of the sound subcarrier would be to ensure that the vision and sound signals reach their respective threshold levels simultaneously when the carrier-to-noise ratio (c.n.r.) is reduced; this may be important under fading conditions, but it is thought that fading should not be severe in the case of direct satellite broadcasting. If such a criterion were to be adopted, the required relative amplitude of the sound subcarrier would depend on the overall bandwidth.

The choice of subcarrier amplitude may affect the impairment caused by co-channel interference on the picture, because the available peak-to-peak vision deviation is dependent on the subcarrier amplitude. For the present investigation, various vision-to-sound ratios were used, but the overall peak-to-peak deviation (defined in Fig. 3) was maintained at 10 MHz (except for two tests, when it was 21 MHz).

3.3. Pre-emphasis

It is normal practice[3] on radio-relay f.m. television links to apply pre-emphasis to the video signal. Advantages claimed for pre-emphasis are that differential-gain and differential-phase distortion are reduced, and frequency stabilisation is simplified. However, these factors relate to instrumental imperfections, and are not basic attributes of the f.m. system. The use of pre-emphasis will tend to increase any intermodulation between the luminance and chrominance components unless the low-frequency deviation is appropriately reduced. A CCIR document[4] reports some experiments which are aimed at establishing pre-emphasis parameters for a colour television transmission by satellite, but the results are inconclusive. In these experiments the r.f. bandwidth was sufficiently high to avoid luminance-chrominance intermodulation, caused by bandwidth restriction. However, the optimum in practice may correspond to a somewhat smaller bandwidth.

For the purpose of the present investigation into co-channel interference, no pre-emphasis was used, apart from a limited test to be described in Section 5.4.

3.4. Suppression of d.c. component

On radio-relay links it is found convenient to suppress the d.c. component by employing a.c. coupling in the modulator. The d.c. is effectively restored at the receiver by means of a clamp. One disadvantage of such a system is that the maximum frequency excursion, and hence the bandwidth, is increased, particularly if pre-emphasis is not employed. It is unlikely that there will be any difference in the protection ratios required against co-channel interference for a.c. and d.c. coupling, although it is possible that different impairments may be obtained for particular combinations of wanted and interfering pictures. In order to be able to use available equipment, the tests described in this report were carried out with a.c. coupling. On the still pictures used in the subjective tests to be described in Section 5, the mean frequency shift introduced by the use of a.c. instead of d.c. coupling is less than 1% of the peak-to-peak deviation. Therefore the results for still pictures would have been substantially unaffected if measures had been taken to use d.c. coupling instead of a.c.

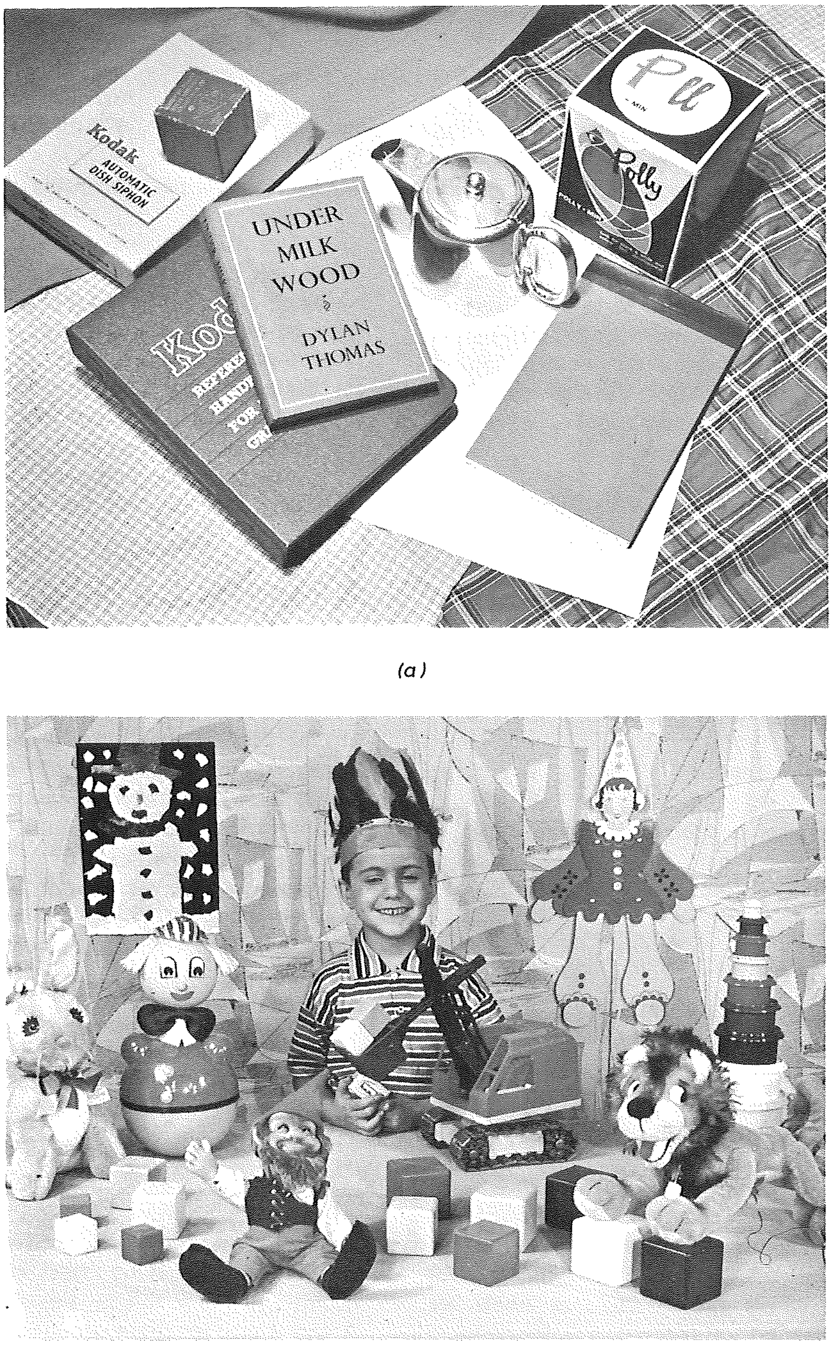
3.5. Energy dispersal

In frequency-modulated multi-channel telephony systems energy dispersal waveforms are usually added to each channel,[5] to reduce the peak value of the spectral lines under conditions of light channel loading. Energy dispersal may also be desirable for satellite links carrying television signals if they are operating in the same band as telephony services. However, in the case of television signals interfering with television signals such measures are probably unnecessary, because the presence of synchronising pulses, together with colour and sound subcarrier components, will in any case provide a measure of energy dispersal. There may be certain combinations of wanted and interfering pictures for which additional energy dispersal waveforms would reduce the visible effects of interference, but it is thought that, in general, the benefit obtained would be insufficient to justify the additional circuits required at the receiver to remove the dispersal waveform. As mentioned in Section 2, previous work has tended to confirm that additional energy dispersal waveforms have little effect on the protection ratio required against co-channel interference between f.m. television signals.

4. Experimental arrangement

4.1. Equipment

A block diagram of the arrangement used for the tests is shown in Fig. 1. The 70 MHz modulators and demodulator are commercial units. They are designed for a peak-to-peak deviation of 8 MHz, but this can be extended to 10 MHz without difficulty. A still greater extension is possible if some degradation in performance is acceptable. For the purpose of assessing the effect of co-channel interference, it was found to be possible to increase the deviation to about 21 MHz.



(a)

(b)

Fig. 2 - Still slides used for tests

The vision and sound output s.n.r.s were measured, when random white noise was added between the modulator and demodulator, and the results agreed closely with those predicted theoretically.

4.2. Viewing conditions

The pictures were displayed on a 19 in. colour monitor, set to have a peak white luminance of about 55 candela/m^2. The ambient illumination at the screen was about 5·4 lux. The observers sat at a distance of six times the picture height.

Two still slides were used for most of the tests, as shown in Fig. 2. Slide A consisted of a number of objects arranged so that there were fairly large areas of various colours. Slide B contains a wide range of colours, and a greater amount of detail than slide A.

In addition to the still slides, some of the tests used a moving picture derived from a video tape recorder. It consisted of an excerpt from the programme 'Music, Music, Music', and it contained a good range of colours including flesh tones.

4.3. Observers

Different numbers of observers were used for the various tests, but generally there were eight to twelve. At each sitting, however, there were no more than four. The observers can be divided into three broad categories, viz., experts (*a*), technical (*b*), and non-technical (*c*). Category (*a*) indicates that the observer is experienced in critically assessing the quality of television pictures; category (*b*) indicates that the observer is employed in a technical capacity, but is not normally required to assess television picture quality; category (*c*) indicates that the observer is neither employed in a technical capacity, nor experienced in critically assessing picture quality. The division into these three categories is inevitably only approximate. The numbers in each category were as follows:

category *a* : 9
category *b* : 10
category *c* : 9

It was not possible to ensure that equal proportions of these categories were used for all the tests, and for the final analysis of the results the assessments of the three categories were grouped together.

4.4. Assessment of impairments

For most of the tests, the observers were asked to assess the impairment of the picture according to the 6-point impairment scale (CCIR Report 405, Note (c)).

1. Imperceptible
2. Just perceptible
3. Definitely perceptible, but not disturbing
4. Somewhat objectionable
5. Definitely objectionable
6. Unusable

The range of interference levels presented was restricted so that the impairment did not exceed about grade 4. This is because for planning purposes the higher impairments are usually irrelevant, particularly in the case of satellite broadcasting, where the interference levels are expected to be fairly constant.

For some tests, a comparative scale was used, viz.,

−1 Worse than
0 Same
+1 Better than

4.5. Peak-to-peak deviation

The nominal peak-to-peak deviation of an f.m. television link is often measured from the tips of the synchronising pulses to peak white, as shown by D in Fig. 3, but for the purposes of this report it is useful to define three other peak-to-peak deviations, and these are illustrated in Fig. 3, for the case of picture modulation by colour bars. D_v is the peak-to-peak deviation of the composite video signal, including colour subcarrier, D_s is the peak-to-peak deviation of the sound subcarrier alone, and D_t is the total peak-to-peak deviation including the video and sound signals.

5. Results of tests

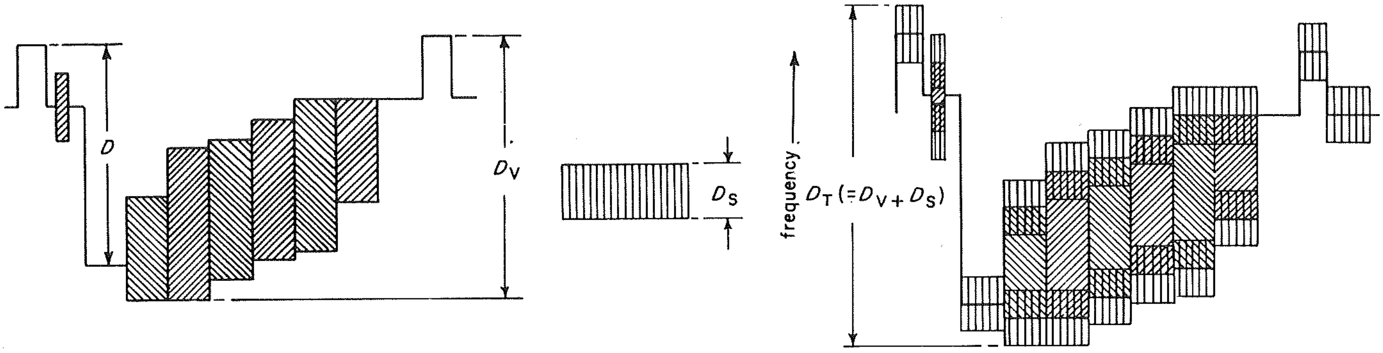
5.1. Repeatability of assessments

In a number of the tests to be described later, some of the conditions were repeated (without telling the observers), so that a measure of the repeatability of the assessments could be obtained, as summarised in Table 1. Column 1 in this table gives the category of the observer, as described in Section 4.3. Columns 2 give the total number, n, of pairs of identical-condition assessments upon which the 'repeatability scores' in Column 3 are based. The repeatability score is defined as the mean of the differences between the first and second assessments of the same condition.

Table 1 suggests that there is no significant difference between the repeatability scores of the three observer categories.

5.2. Effect of modulation of interfering signal

As mentioned in Section 2, previous work has suggested that modulation of the interfering signal has a relatively unimportant effect on the impairment. It was decided to check this by assessing the impairment on slides A and B and on the moving picture, the interfering carrier



Composite colour video signal

Sound subcarrier

Composite signal with sound

Fig. 3 - Definition of peak-to-peak deviations

TABLE 1

Repeatability Check

1	2			3		
Category of observer	n			Repeatability score		
	Still 'A'	Still 'B'	Moving picture	Still 'A'	Still 'B'	Moving picture
a	12	12	12	0·50	0·75	0·42
a	6	6	6	0·50	0·33	0·67
a	6	6	6	0·67	0·33	0·33
Mean (*a*)				0·56	0·47	0·47
b	12	12	12	0·42	0·42	0·59
b	12	12	12	0·42	0·42	0·50
b	6	6	6	0·33	0	1·50
b	6	6	6	0·33	0·17	0·50
Mean (*b*)				0·37	0·25	0·77
c	12	12	12	0·33	0·58	0·67
c	12	12	12	0·18	0·84	0·50
c	12	12	12	0·50	0·50	0·92
Mean (*c*)				0·34	0·64	0·70

being either c.w. within 100 kHz of the nominal centre frequency of 70 MHz, or fully modulated by colour bars and sound subcarrier. Thirteen observers assessed the impairment on stills A and B, and twelve assessed the impairment on the moving picture. For these tests the deviations, as defined in Fig. 3, were D_v = 8 MHz and D_s = 2 MHz. For convenience, the impairment grade will be denoted by I, and the ratio wanted signal/unwanted signal (in dB) by P. For each assessment, I can have only integral values from 1 to 6, but when the mean value of a number of observers' assessments is calculated, I is permitted to have fractional values. Then, I can be related to P by a quadratic curve chosen to minimise the sum of the squares of the deviations of the measured values of I from the curve. The 'best-fit' curve was calculated for the results of each test, and the difference between the appropriate curves for modulated interference and the curves for c.w. interference was obtained for each picture. The results are given in Fig. 4. This shows that for slide B and the moving picture there is little difference, but for slide A the modulated interference caused noticeably greater impairment than the c.w. interference. This suggests that spectral components away from the nominal centre frequency were significant.

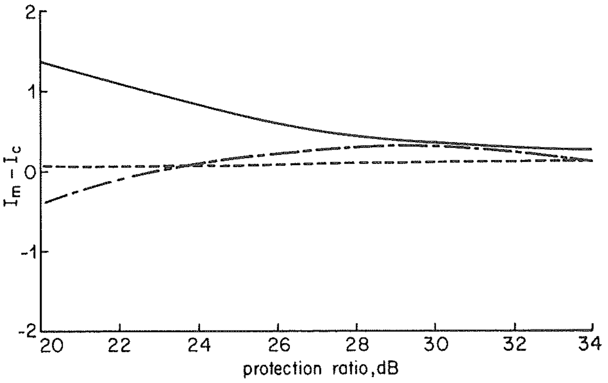


Fig. 4 - Difference between c.w. and modulated interferences

I_m = impairment grade with modulated interference

I_c = impairment grade with c.w. interference

—— Slide A – – – Slide B —·— Moving picture

Further assessments were made on slide A, an interfering c.w. signal being varied in frequency over the deviation range of the wanted signal. The value of D_v of the wanted signal was 8 MHz. The sound subcarrier was not present for these experiments. The frequency of the interfering carrier was varied from about 65 MHz to about 75 MHz. Four frequencies corresponding to two minima and two maxima of the impairment were found in a preliminary experiment, first with the wanted picture in colour, and then in monochrome. It may be noted that the frequencies for minimum and maximum impairments were different for the colour picture than for the monochrome picture. Six observers were then asked in turn to adjust the level of the interference at each of the predetermined frequencies to obtain grade 2 (just perceptible) impairment.

The mean assessment of the relative interfering level in these tests varied from 25·5 dB to 41·1 dB for colour, and from 22·5 dB to 28·7 dB for monochrome. Thus, there is a much greater range of impairment for colour than for monochrome, and moreover, it appears that a lower average interfering level is demanded for colour.

This conclusion was confirmed by a corresponding assessment (by one observer) of the effect of c.w. interference on a wanted picture consisting of 95% saturated colour bars. Inspection of the frequency spectrum on an analyser, and the relation of this display to the picture impairment, showed that the maximum impairment on a particular colour bar was produced when the interfering carrier coincided with one of the first-order colour sidebands on either side of the frequency defining the luminance level of the colour bar. Although a particular combination of picture content and interfering c.w. frequency can demand a high protection ratio, it is unlikely that such combinations would occur frequently, and in general when the interfering signal is frequency-modulated, the difference between the impairment of a picture on a colour receiver and that on a monochrome receiver may be expected to be much less noticeable. This was confirmed by further subjective experiments. In this case, still pictures A and B were assessed by three observers. The pictures were shown in both colour and monochrome. The interfering carrier was frequency-modulated by colour bars. The relative interference level was varied between 20 and 30 dB, corresponding to impairment grades of about 1 to 4. No significant difference was found between the colour and monochrome assessments. If the wanted and interfering signals were modulated to equal deviations by identical programmes, a somewhat increased protection ratio may, in some circumstances, be required. However, in practice it is likely that there would be some time difference between the two modulating signals, and this would tend to create a similar situation to that arising when the wanted and interfering signals are modulated by different programmes.

5.3. Relationship between impairment and interfering level

Since in a practical case the interfering signal will be modulated for most of the time, it is reasonable to plan on this assumption, and the results to be given in this section all apply to a frequency-modulated interference. As in Section 5.2, it is convenient to express the relationship between interference level and impairment by a curve defined by a second-order polynomial. Thus, using the same symbols as before, we put

$$P = \alpha + \beta I + \gamma I^2$$

Tests were carried out for stills A and B, and for the moving picture. Values of D_v (see Fig. 3) varied from 6 MHz to 17 MHz, and the corresponding values of D_s from 1 MHz to 4 MHz. The values of α, β, γ are given in Table 2, together with the standard deviation, which refers to the deviation of the best-fit curve from the points corresponding to the mean assessments. It does not include the effect of the standard deviation of the individual assessments.

If we take the mean values of α, β, γ for D_v = 8 MHz, we have

$$\alpha \overset{\frown}{=} 45{\cdot}0$$
$$\beta \overset{\frown}{=} -9{\cdot}4$$
$$\gamma \overset{\frown}{=} 0{\cdot}7$$

so that the mean protection ratio for grade 2 impairment becomes 29 dB.

Taken individually, the protection ratios for the three different pictures (for grade 2 impairment) are

Still A : 30·3 dB
Still B : 30·8 dB
Moving : 25·9 dB

TABLE 2

Values of α, β, γ

Wanted picture	D_v MHz	D_s MHz	Number of observers	α	β	γ	Standard Deviation dB
Still A	6	4	12	52·86	−13·85	1·465	1·16
Still A	8	2	13	46·46	− 9·897	0·9166	1·20
Still A	9	1	8	42·85	− 5·837	0·2157	0·47
Still A	17	4	8	35·52	− 7·455	0·4648	0·12
Still B	6	4	12	54·32	−16·35	1·967	1·76
Still B	8	2	13	33·80	1·416	−1·458	2·88
Still B	9	1	8	46·48	− 7·243	0·336	0·44
Moving	6	4	12	49·91	−16·69	2·352	2·01
Moving	8	2	12	54·65	−19·70	2·654	2·31
Moving	9	1	8	68·18	−35·87	6·32	0·48
Moving	17	4	8	24·77	− 3·743	0·079	1·91

For planning purposes it is desirable to provide a small 'safety factor' to allow for the occurrence of particularly sensitive pictures. It is suggested that this could be achieved by adding 2 dB to the value of α, which then becomes 47·0 at D_v = 8 MHz. The resulting protection ratio versus impairment curves is shown in Fig. 5, together with points giving the actual mean test assessments.

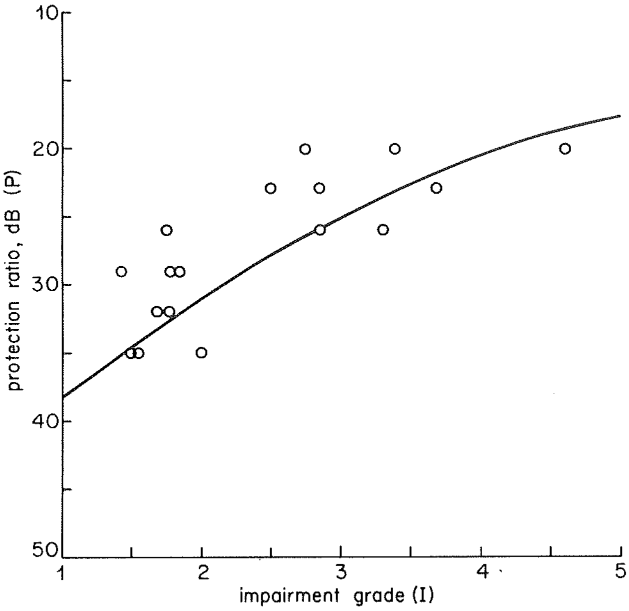


Fig. 5 - Protection ratio vs. impairment curve, D_v = 8 MHz

o Mean of observer assessments

— Calculated from Equation (1)

In order to extend the results obtained for one deviation to other deviations, it would be convenient to make the value of α a simple function of the deviation. Previous work[2] has suggested that the effect of deviation can be taken into account by adding 1 dB to the protection ratio for each 1 dB reduction in deviation. As this is such a simple rule, it is interesting to apply it to the results of the present tests. Fig. 6 shows the results for D_v = 6 MHz, and Fig. 7 for D_v = 17 MHz. It may be seen that fairly good agreement is obtained. Thus, the following formula is tentatively proposed for relating the protection ratio P(dB) to the impairment grade I, when the peak-to-peak deviation of the vision component of the signal (in MHz) D_v is:

$$P = 47 - 20\log_{10}\frac{D_v}{8} - 9{\cdot}4I + 0{\cdot}7I^2 \qquad (1)$$

5.4. Effect of pre-emphasis

As discussed in Section 3.3, the decision whether or not to use pre-emphasis of the vision signal may be governed by factors other than its effect upon noise, and in any case the optimum characteristic to employ is not certain. It is nevertheless desirable to investigate possible effects of pre-emphasis on the protection ratio required against co-channel interference. A limited test was therefore carried out, in which subjective comparisons were made by 8 observers on slide A. The observers were shown the picture alternately with and without pre-emphasis of the wanted and interfering signals, and they were asked to state which condition they preferred. A score of +1 indicated a preference for pre-emphasis, −1 a preference for no pre-emphasis, and 0 indifference. The pre-emphasis characteristic employed was in accordance with CCIR Recommendation 405, for a monochrome 625-line system, except that the frequency of 0 dB insertion loss was raised from 1·5 MHz to 2 MHz, to reduce the possibility of the assessments being affected by non-linear distortion effects.

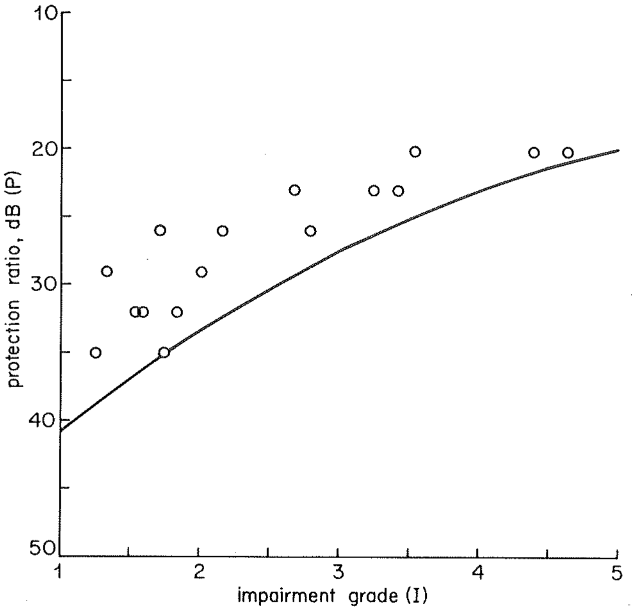


Fig. 6 - Protection ratio vs. impairment curve, D_v = 6 MHz

o Mean of observer assessments

— Calculated from Equation (1)

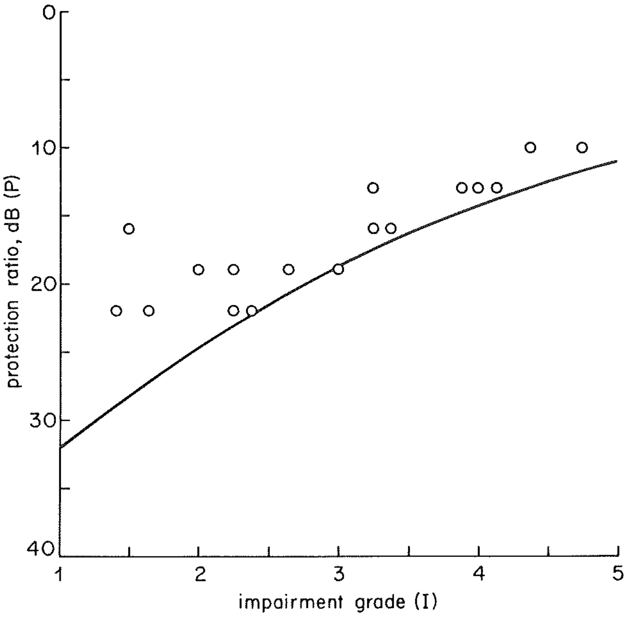


Fig. 7 - Protection ratio vs. impairment curve, D_v = 17 MHz

o Mean of observer assessments

— Calculated from Equation (1)

Three levels of interference were assessed, viz. −23, −29 and −32 dB, as well as a control test with no interference (−∞). The value of D_v was 6 MHz. The mean assessment scores are shown in Table 3.

TABLE 3

Mean Preference for Pre-emphasis

Interference level, dB	−23	−29	−32	−∞
Mean score	− 0·75	− 0·625	− 0·125	−0·25

Although the results may be confused by the score of −0·25 in the control case of no interference, they indicate that in this limited test there was a preference for having no pre-emphasis. In the absence of agreed proposals for specific pre-emphasis parameters, this investigation was not pursued further.

5.5. Effect of inversion of interfering modulation

Unless the synchronising pulses of the wanted and interfering modulation are locked in time, it is unlikely that the protection ratio will depend significantly on whether the modulation is positive-going or negative-going. In order to provide some check on this tentative conclusion, four observers were asked to assess their preference for inverted or non-inverted modulation of the interference. A score of +1 was given if a non-inverted signal was preferred (i.e. if the impairment caused by the interference was less), and −1 if the inverted signal was preferred. Five interference levels were assessed, on slides A and B, the interfering signal being colour bars. The results are given in Table 4.

This test tends to confirm that, on average, inversion of the interfering modulation produces no significant change in the protection ratio required, although a difference may be observed on particular pictures.

5.6. Comparison with random noise

It is interesting to compare the impairment produced by co-channel interference with that caused by the addition of random noise added to the r.f. signal. As a first approximation, it may be suggested that random noise would produce a similar overall impairment for the same mean interfering signal power to that produced by a frequency-modulated carrier.

Subjective tests were carried out by eight observers, on slides A and B, random noise being added to the r.f. signal, the overall bandwidth being limited by a band-pass filter to 22 MHz (to the −3 dB points). The value of D_v was 8 MHz. The picture impairment was assessed in the same way as the co-channel interference.

The results of this test are shown in Fig. 8, together with the curve calculated according to the co-channel interference formula in Equation (1) for D_v = 8 MHz. It may be seen that there is good agreement between the curve and the experimental points. The video unweighted signal-to-noise ratio, defined in the usual way, is 8·2 dB greater than the carrier-to-noise ratio given in Fig. 8.

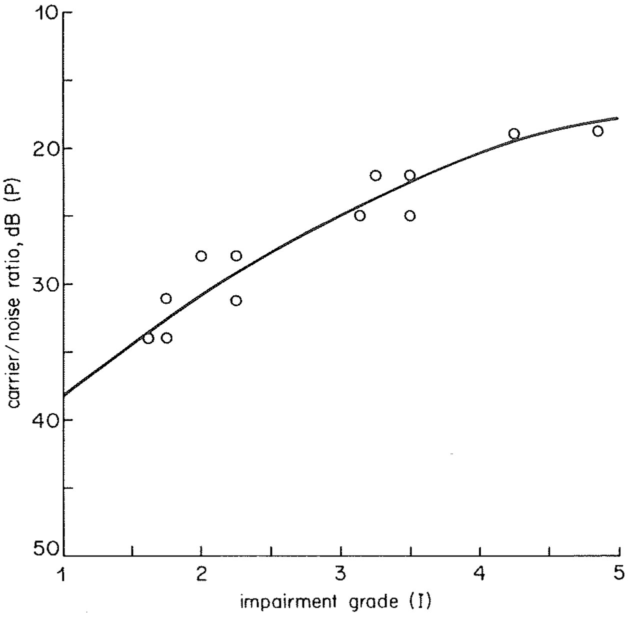


Fig. 8 - Carrier/noise ratio vs. impairment, D_v = 8 MHz

○ Mean of observer assessments

— Calculated from Equation (1)

5.7. Effect on sound

So far in this report, the emphasis has been on the impairment of the vision signal, and there has been little reference to the accompanying sound. A sound programme was present during most of the tests, but it was thought that it may have been too confusing to ask the observers to critically assess the impairment of the sound as well as the picture. However, during the course of some of the tests the observers were invited to comment if they considered the sound to be degraded by the interference. The general conclusion was that with a total deviation D_T of 10 MHz, when D_s = 1 MHz annoying clicks could be heard on the sound programme even when the picture impairment was quite small. When D_s = 2 MHz, the sound was unaffected even at fairly high picture impairments. Thus, the proposed value of 13% (see Section 3.2) for the relative amplitude of the sound subcarrier appears to form a good basis for a practical system.

TABLE 4

Mean Preference for Modulation Inversion

Interference level, dB	−20	−23	−26	−29	−32
Slide A mean score	− 0·5	− 0·75	− 0·75	− 1·0	− 0·25
Slide B mean score	+ 0·75	+ 0·5	+ 1·0	+ 0·75	+ 0·25

5.8. The use of over-deviation

So far in this report it has been assumed that the maximum permissible peak-to-peak deviation is related to the maximum modulation frequency and the r.f. bandwidth by the usual Carson formula. However, it is possible that the degradation of the vision and sound transmission may be acceptably small if, for a given bandwidth and maximum modulation frequency, the deviation is increased beyond that required by Carson's criterion, and this could have beneficial effects on the noise performances of the system. Some preliminary subjective assessments were made, and these indicated that, with the r.f. bandwidth limited to 22 MHz by a filter, the total deviation could be increased from 10 MHz to about 13 MHz, without introducing significant degradation of the picture. Using Equation (1), this may be expected to result in a decrease of about 2 dB in the protection ratio required, but other factors may reduce this potential benefit.

6. Conclusions

In an f.m. system suitable for direct television broadcasting from a satellite, it is suggested that to simplify the adaptation of Standard I receivers the sound signal should be transmitted by a frequency-modulated 6 MHz subcarrier added to the composite video signal. If such a system were used, the amplitude of this subcarrier would preferably be such as to produce a peak-to-peak deviation of the main carrier of about 13% of the total.

Based on subjective tests, an empirical formula has been derived, relating the co-channel protection ratio required for a given impairment grade to the peak-to-peak deviation of the vision signal. This is given in Equation (1). The results apply to colour transmissions, in which the interfering picture is different from the wanted picture. It is expected that the protection ratio for monochrome transmissions will be similar.

7. References

1. Satellite broadcasting: spectrum efficiency of television services in the 12 GHz band. BBC Research Department Report No. 1970/38.

2. CCIR, Documents of the XIIth Plenary Assembly, New Delhi 1970, Vol. IV, Pt. 1, Report 449.

3. CASTELLI, E., ANDERSON, W.N., BRUN, G., *and* GALLAGHER, J.C. Radio-relays for television, Vols. 1 and 2, EBU Technical Monograph, 1969, No. 3110.

4. CCIR Document IV/258-E, Period 1966–1969, May 1969.

5. The effects of an energy-dispersal signal, used for interference reduction, on the performance of an F.M. system. Post Office Research Department Report, 1969, No. 98.

6. Modulation systems for television: theoretical comparison of noise performance, with and without pulse coding. BBC Research Department Report No. 1970/39.

APPENDIX

Amplitude of Sound Subcarrier

Figure 9 shows the demodulating arrangement envisaged. At any particular point in the circuit,

$$\text{let } r = \frac{\text{peak-to-peak signal voltage}}{\text{r.m.s. unweighted noise voltage}}$$

At points where there is a sinusoidal carrier, we will use the symbol R, where

$$R = \frac{\text{r.m.s. carrier voltage}}{\text{r.m.s. unweighted noise voltage}}$$

When the sound subcarrier is present with the composite video signal, so that the 'carrier' forms part of a 'signal',

$$r = R + 9 \quad \text{(in dB)} \qquad (1)$$

Numerical subscripts to r and R will be used to denote the values at the points indicated by the numbers in Fig. 9. At points where the vision and sound are both present, the superscript ^{v} will be used to indicate the vision part of the signal, and the superscript ^{s} will indicate the sound part of the signal.

It is assumed that when the vision luminance-to-unweighted-noise ratio is 42 dB, the sound signal-to-unweighted-noise ratio, defined as

$$20 \log_{10}\left(\frac{\text{r.m.s. audio voltage at maximum modulation}}{\text{r.m.s. unweighted noise in a 15 kHz bandwidth}}\right),$$

should be 60 dB.

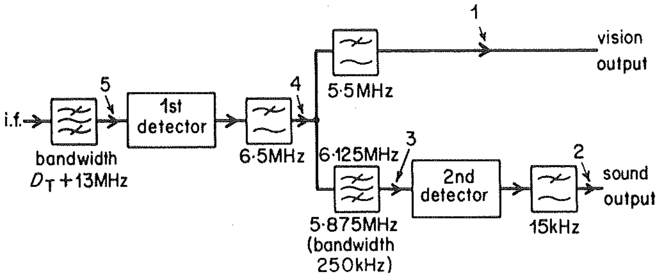


Fig. 9 - F.M. demodulation arrangement

Then, since the luminance signal occupies 60% of the total available voltage swing of the composite vision waveform (without a sound subcarrier), we have at the vision and sound output terminals in Fig. 9:

$$r_1 = 46{\cdot}5 \text{ dB} \qquad (2)$$

$$r_2 = 69{\cdot}0 \text{ dB} \qquad (3)$$

The relationship between the demodulated s.n.r. and the carrier-to-noise ratio before demodulation is derived in the appendix of reference 6. From this relationship we find that for a peak-to-peak f.m. deviation of the sound subcarrier of 100 kHz, noise bandwidths as indicated in Fig. 9, and assuming an improvement of 2 dB by using 50 μs pre- and de-emphasis in the audio chain,

$$R_3 = 33{\cdot}5 \text{ dB} \qquad (4)$$

At point 4, the sound carrier is combined with the composite video signal, and the noise bandwidth is 6·5 MHz. Moreover, because of the triangular noise voltage spectrum from the first detector, the noise density in the sound channel is about 4 dB greater than the mean noise density. It is assumed that no pre-emphasis is applied to the composite signal. Therefore, bearing in mind Equations (2) and (4), we have

$$r_4{}^{\mathrm{v}} = r_1 - 10 \log_{10} \left(\frac{6{\cdot}5}{5{\cdot}5}\right)^3$$

$$= 46{\cdot}5 - 2{\cdot}2 \text{ dB}$$

$$= 44{\cdot}3 \text{ dB}$$

$$r_4{}^{\mathrm{s}} = R_4{}^{\mathrm{s}} + 9 \text{ (from Equation (1))}$$

$$= \left(R_3 - 10 \log_{10} \frac{6{\cdot}5}{0{\cdot}25}\right) + 9 \text{ dB}$$

$$= 33{\cdot}5 - 14{\cdot}1 + 9 \text{ dB}$$

$$= 28{\cdot}4 \text{ dB}$$

But to allow for the triangular voltage spectrum, $r_4{}^{\mathrm{s}}$ must be increased by 4 dB relative to $r_4{}^{\mathrm{v}}$

$$\therefore r_4{}^{\mathrm{v}} - r_4{}^{\mathrm{s}} = 44{\cdot}3 - 28{\cdot}4 - 4 \text{ dB}$$

$$= 11{\cdot}9 \text{ dB}$$

Thus, if α is the proportion of the total deviation occupied by the sound signal, so that $(0{\cdot}6)(1-\alpha)$ is the proportion occupied by the luminance component of the vision signal then

$$\frac{(0{\cdot}6)(1-\alpha)}{\alpha} = 3{\cdot}94 \quad \text{(i.e. } 11{\cdot}9 \text{ dB)}$$

$$\therefore \quad \alpha \simeq 0{\cdot}13$$

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